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AGRICULTURAL MEMORANDUM NO 348

Accumulated degree-days below variable bases

W H HOGG and J W DAVIES

1. Introduction

1.1 Accumulated temperatures below a given base may be regarded as the integrated deficiency of temperature over a period of time. In glasshouse heating these are often referred to as the degree-days below the base and in other contexts the term cold units has been used.

Accumulated values of degree-days are used to design glasshouse heating systems, see MAFF Bulletin 115 (1964). Davies (1966, 1967, 1968a, 1968b) has given tables of accumulated degree-days below selected bases for various stations in the west of England and in Wales. The base temperatures depend upon the crops grown and have been determined experimentally or by experience. They are normally assumed to be constant throughout the 24-hr cycle, although they may be varied at different stages of crop development and growth.

2. Diurnal variations of base temperature

Recommendations for glasshouse growing now usually differentiate between the day and night temperatures required, see for example the blueprint given for tomatoes by Smith (1966). This implies that the base temperature for estimating accumulated degree-days should also be varied and this memorandum describes a method which has been devised to allow for this without complicated calculations.

3. Summary of method

Curves were constructed of mean hourly temperatures for individual months at 4 stations and totals of degree-hours below various day and night base temperatures were computed graphically. These totals were related by linear equations to 24-hour values for the same bases and generalized factors were derived to permit the rapid estimation of degree-days from existing data, using variable base temperatures.

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4. Data. The following data were used:

4.1 Monthly values of hourly average temperatures for

Plymouth	1949-64
Cardiff	1957-66
Thorney Island	1959-66
Boscombe Down	1959-66

4.2 Degree-days below bases 40-70°F by 5°F steps for stations in the South-west and West Midland Regions and for Wales, see Davies (1966 et seq). The method described by Shellard (1959) was used to compute these.

Note: All workings in this paper are in degrees F, to be consistent with those given by Davies.

5. Diurnal distribution of degree-hours below stated base temperatures

5.1 Graphs of mean hourly temperature were drawn for January, April, July and October, a preliminary inspection having shown that these could reasonably be taken to apply to the month on each side. The mean daily temperature T was calculated for the month and graphical estimates were made of the number of degree-hours which occurred below T, T + 1, T - 1, T + 2, T - 2 until the base was above the maximum or below the minimum of the curve. For base values above the curve maximum, degree-hour values were estimated for 5° steps up to 70°F. When the base value was below the curve minimum the number of degree-hours below that base was zero. These estimates were made for individual hours and were later apportioned to various lengths of day and night.

5.2 Simplifying assumptions were made as to the lengths of day and night and subsequent workings were based upon daylengths of 8 hr (0800-1600), 12 hr (0700-1900) and 16 hr (0400-2000) roughly covering the seasonal range in southern England. All times are GMT.

5.3 The percentage of degree-hours which fell in the days of various lengths for each of the estimates of para 5.1 were computed.

Fig.1 gives a specimen curve showing methods of estimation for April at Boscombe Down for temperature T = 47.1 and Table I contains the daytime percentage of degree-hours for all stations and months.

Table I Percentage of degree-hours to occur within days of various lengths

Station	T-6	T-5	T-4	T-3	T-2	T-1	T	T+1	T+2	T+3	T+4	T+5	T+10	T+15	T+20	T+25
JANUARY 8-hr day																
Plymouth						26	18	17	19	22	26	26	30	33	33	33
Cardiff						1	11	14	15	20	25	26	29	32	32	32
Thorney Island						21	16	16	17	19	23	25	29	31	33	33
Boscombe Down						15	16	16	18	18	23	25	29	30	33	33
JANUARY 12-hr day																
Plymouth						53	29	28	32	37	42	42	46	50	50	50
Cardiff						15	20	24	29	35	40	42	46	48	48	48
Thorney Island						43	27	28	31	35	39	42	45	48	50	50
Boscombe Down						35	27	27	30	34	38	41	46	46	50	50
APRIL 12-hr day																
Plymouth					4	7	10	10	14	18	22	27	38	42	43	
Cardiff					2	5	8	10	13	17	20	26	37	42	43	
Thorney Island					3	5	7	9	12	14	17	24	36	42	43	
Boscombe Down				2	5	6	9	10	12	14	16	20	34	40	42	
APRIL 16-hr day																
Plymouth				76	59	50	46	43	45	47	50	54	60	61	62	
Cardiff				69	52	46	43	43	44	46	48	51	59	61	62	
Thorney Island			89	59	49	44	42	42	43	44	46	51	58	61	62	
Boscombe Down			73	58	49	45	43	43	43	44	45	48	56	61	61	
JULY 12-hr day																
Plymouth						2	4	7	10	14	20	25	39	42		
Cardiff						1	3	6	9	12	18	22	36	42		
Thorney Island						2	4	6	7	11	14	18	33	39		
Boscombe Down					1	2	4	6	7	9	10	13	29	36		
JULY 16-hr day																
Plymouth			76	54	45	41	39	39	40	43	47	50	60	61		
Cardiff			54	42	37	36	35	36	38	41	45	47	57	61		
Thorney Island		72	53	46	43	39	38	37	38	41	44	46	56	59		
Boscombe Down	58	46	42	39	37	36	36	37	37	39	39	41	53	57		
OCTOBER 8-hr day																
Plymouth						3	5	7	9	10	13	18	27	27	28	
Cardiff						2	5	7	9	10	12	18	26	27	28	
Thorney Island					1	3	4	6	7	9	10	10	22	26	26	
Boscombe Down					1	3	5	6	8	9	10	12	22	26	27	
OCTOBER 12-hr day																
Plymouth					13	15	15	17	21	23	28	33	42	43	45	
Cardiff					8	12	14	17	20	22	26	33	42	43	45	
Thorney Island				11	13	13	14	15	17	21	23	25	38	42	42	
Boscombe Down				8	12	13	14	15	18	20	22	27	37	42	43	

6. 12-hour days

6.1 If a crop has a day temperature requirement of d, a night temperature requirement of n and the day is taken as 12 hours, it is simple to calculate the following 24-hour values from Shellard (1959) or from the half-monthly values given by Davies (1966 et seq).

6.1.1 The number of degree-days below base temperature d. Let this be designated D.

6.1.2 The number of degree-days below base temperature n. Let this be designated N.

6.1.3 The number of degree-days below base temperature of $\frac{d + n}{2}$. Let this be designated $\frac{D + N}{2}$.

6.2 It is also possible to obtain an estimate of the true value using base temperatures d for 0700-1900, n for 1900-0700 and the information given in Table I. Let this be designated K. An example is given in Table II.

Table II Example of calculation to find K

Plymouth - January

Mean temperature (T) = 42.5

		Day	Night
	Base temperature	60 = T + 17½	50 = T + 7½
1.	Degree days in 24 hours (see Agric. Memo No 175)	775	340
2.	Day (or night) percentage (see Table I)	50	56
3.	Day (or night) number of degree-days (line 1 x line 2)	387	190
	K (day + night)	577	

6.3 The following generalized values of temperatures recommended for glasshouse crops were used as a basis for computations:

Table III Glasshouse heating requirements

Crop	Stage	Period	Day Temp	Night Temp	
Tomatoes	Seedling/young plant	1-31 Dec	64	58	
	Truss expansion	1-15 Jan	64	60	
	Fruit development/ early ripening	15 Jan-15 Apr	68	60	
	Main ripening	15 Apr-30 June	64	62	
Lettuce	Propagation	1-15 Oct	55	50	
	Planting out to early rosette	15 Oct-15 Nov	60	55	
	Rosette to cutting	15 Nov-31 Jan	63	45	
Carnations		1 Nov-30 Apr	60	50	
		1 May-31 Oct	60	54	
Chrysanthemums	Propagation	1-28 Feb	60	55	
	Growing on (bud initiation)	1-22 Mar	65	58	
	Budding to flowering	22 Mar-22 May	65	58	(dropping by 2°F per half month at night to improve flower quality)
Cucumbers	Growing on to cropping	1 Dec-28 Feb	65	62	
	Main cropping	1 Mar-31 May	65	60	

Dates are approximate averages

6.4 Values of D, N, $\frac{D + N}{2}$ and K were computed for the 4 stations and crop totals are given in Table IV, which also contains the mean of D and N, designated mean (D, N).

Table IV Degree-day crop totals for 4 stations based on 12-hour day

Crop	Station	D	N	$\frac{D+N}{2}$	Mean (D, N)	True Value, K
Tomatoes	Plymouth	3791	2678	3211	3232	3230
	Cardiff	4244	3143	3696	3694	3684
	Thorney Island	4128	3004	3562	3567	3553
	Boscombe Down	4424	3307	3866	3865	3870
Lettuce	Plymouth	1746	381	991	1063	1082
	Cardiff	2117	659	1345	1387	1385
	Thorney Island	2062	628	1288	1345	1356
	Boscombe Down	2333	839	1555	1586	1612
Carnations	Plymouth	3347	1207	2193	2276	2224
	Cardiff	4042	1747	2828	2895	2782
	Thorney Island	3776	1596	2705	2686	2613
	Boscombe Down	4317	2003	3095	3160	3081
Chrysanthemums	Plymouth	1894	1025	1434	1460	1444
	Cardiff	2087	1218	1633	1652	1633
	Thorney Island	2003	1151	1557	1578	1560
	Boscombe Down	2142	1268	1684	1706	1708
Cucumbers	Plymouth	3407	2677	3042	3042	3036
	Cardiff	3873	3143	3508	3508	3509
	Thorney Island	3772	3045	3409	3409	3418
	Boscombe Down	4057	3327	3692	3692	3703

6.5 The values in Table IV show that D and N alone should not be used to estimate the true value but that $\frac{D + N}{2}$ and mean (D, N) both give estimates very close to the true value.

7. 8- and 16-hour days

7.1 It was assumed that D, N and the true value, K, were linked by equations of the form

$$a\,D + b\,N = K$$

The data on which Table IV is based were used to give the values of D, N and K. For this purpose, the 8-hr day was taken as applicable to November, December and January and the 16-hr day to May, June and July. The following combinations of d and n temperature were included to extend the range.

Summer	(16-hr day)	65, 60:	65, 55:	60, 54
Winter	(8-hr day)	70, 60:	70, 55:	70, 50:
		65, 60:	65, 55:	65, 50:
		60, 55:	60, 50:	60, 45

7.2 The 12 equations for the summer and the 36 for the winter were solved by least squares to give the following results:

$$\text{Summer} \quad 0.53\,D + 0.55\,N = K$$
$$\text{Winter} \quad 0.34\,D + 0.65\,N = K$$

These may conveniently be approximated thus:

$$\text{Summer} \quad \frac{D}{2} + \frac{N}{2} = K$$

$$\text{Winter} \quad \frac{D}{3} + \frac{2N}{3} = K$$

8. Check

The approximate coefficients were used to give estimates of K in the 48 equations of 7.2. Table V shows the estimates, expressed as a percentage of the best possible values obtainable by full working, see 6.2.

Table V Estimates of K, expressed as a percentage of the best possible value

	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
Summer	3		1	1	3						1		1	1	1
Winter							1	7	10	11	7				

9. Discussion

For a 12-hr day, the finding that $(\frac{D}{2} + \frac{N}{2})$ gives a close approximation to the true value for K is not surprising as the base temperature is generally well above mean daily temperature, so that variations in the shape of the diurnal curve are of little importance.

The equation for an 8-hr day $\frac{D}{3} + \frac{2N}{3}$ appears logical in giving a 2:1 weighting in favour of the night-time heating but the equation of $\frac{D}{2} + \frac{N}{2}$ for the 16-hr day is at first sight surprising, a weighting towards the daytime heating might have been expected. This is probably because the base temperatures used fall within the range of the highest and lowest mean hourly temperatures so that much of the daytime heat in summer will be provided by the sun and atmosphere.

References

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Shellard H C. 1959. Averages of accumulated temperature and standard deviation of monthly mean temperature over Britain 1921-50. Meteorological Office, Professional Notes No 125

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Any comments or suggestions on this paper should be sent to the authors.

Meteorological Office
MAAS Burghill Road
Westbury on Trym, Bristol BS10 6NJ

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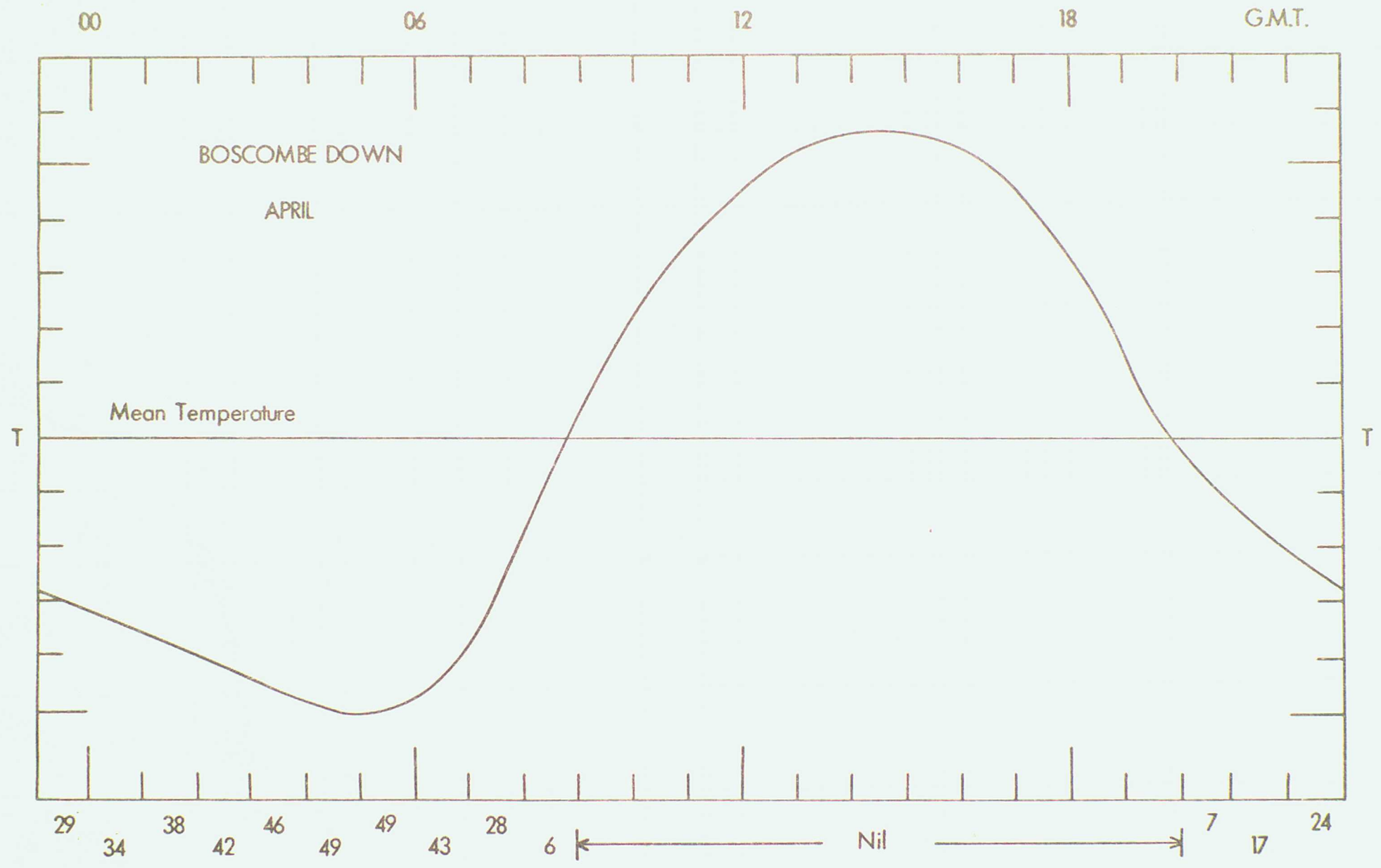

Degree - hours below T (×10)

RW 44532/1/ESTS1 125 9/70 BL